CURRENT CONTROL STRATEGIES

PROPROTIONAL-INTEGRAL-DERIVITIVE (PID) CONTROLLERS

Historically, process control engineers have employed a PID algorithm tuned for no overshoot to move the process variable to setpoint while not allowing overshoot. The downside of using this PID algorithm configuration is that significant time is required for the process variable to reach the setpoint because it reduces the final control element from 100 percent much sooner than optimum for minimum batch cycle times. Thus the cost to produce the product increases because the time to produce the product increases. Another drawback to the PID method is that this method does not include safeguards against process variable overshoot, because the controller output may remain open after the process variable exceeds setpoint resulting from the integral function.

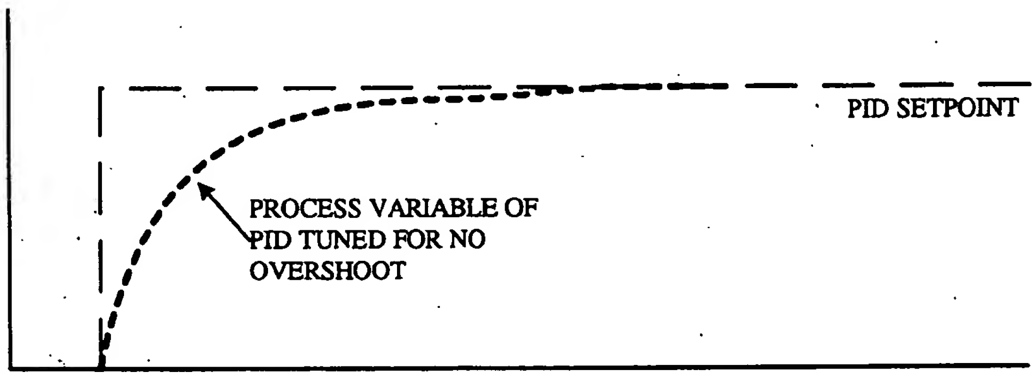


Figure 2: Traditional PID Process Variable Response

Another implementation of the PID includes forcing the controller output to MANUAL until the process variable reaches a percentage of the setpoint, say 80% of setpoint, switching to AUTOMATIC mode at this point and controlling in AUTOMATIC from there. This method approaches the aforementioned goals. However, it has the controller in MANUAL and thus not able to quickly react to unexpected process disturbances and still does not ensure the process variable stays below setpoint. Note: While this technique is seldom published, it is widely utilized in actual applications.

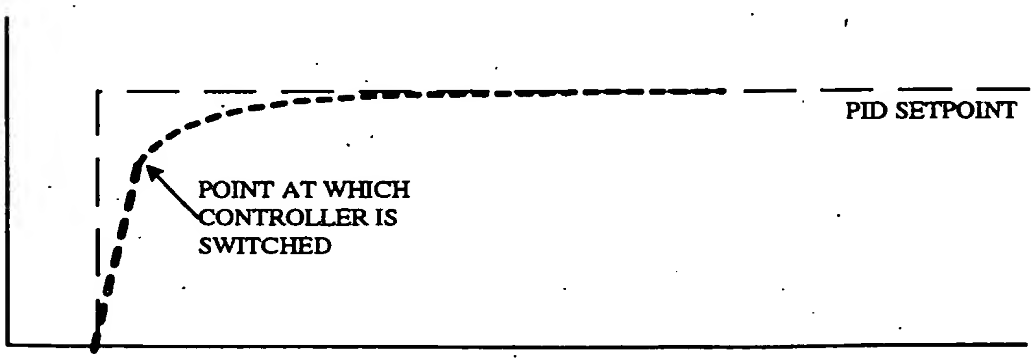


Figure 3 PID Override Performance

Another PID algorithm implementation includes an override of the integral constant – setting the integral constant to 0 until the process variable is close to the setpoint (v). This method provides better resistance to overshoot than the standard PID algorithm but does not include safeguards against overshoot.

RAMP-SOAK (SETPOINT CHARACTIZATION) CONTROLLERS

Ramp-soak controllers characterize the setpoint ascent (dissent) from the current value to the desired final setpoint by "ramping" the physical controller setpoint (vi). The advantage of this method is that the process variable is tightly controlled as the process variable moves to the final setpoint when the controller is properly tuned. However, the minimum time required is still not achieved and (See Fig. 2) the process variable may overshoot.

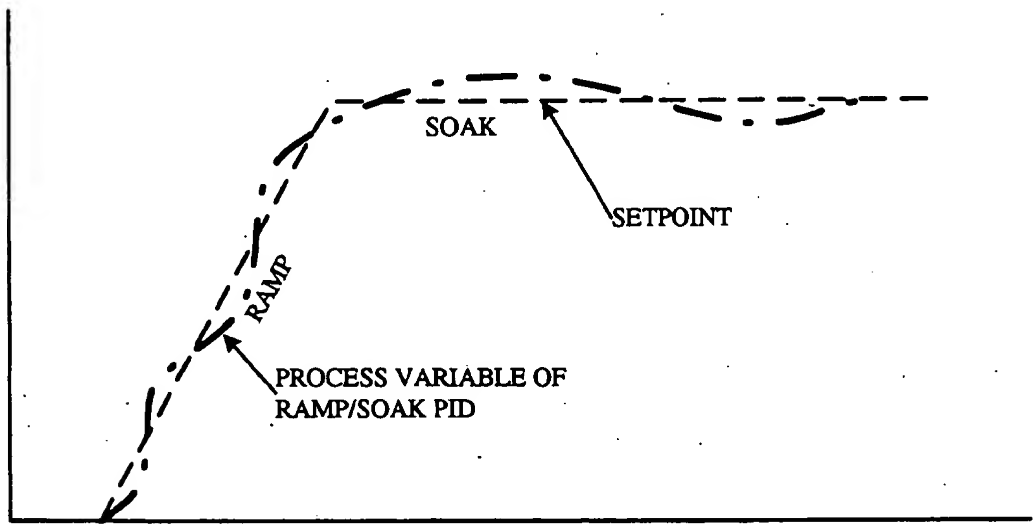


Figure 4: Ramp-Soak Process Variable Performance

MODEL BASED CONTROLLERS

Model based controllers, for example: Dahlin's Algorithm, Model Predictive Control (vii) and Generic Model Controller (GMC) (viii), utilize advanced control algorithms to "model" (hence the name) or characterize the optimum operation of the process. The current process conditions are compared to that model and final control element adjustments are made to achieve the ideal conditions as defined by the model. Model based controllers show great promise in the process control industry. However, these controllers generally are mathematically rigorous (ix). (The details are beyond the scope of this text. For detailed discussions regarding general model based type controllers, please refer to Lee and Sullivan (8).) These controllers also require significant computing resources and thus require significant cost (8)(x). These controllers are also based upon a model developed by an engineer at a specific time. If the engineer is unable to accurately predict the way the process will change over time due to equipment degradation, environmental changes or other factors, suitability of the model is compromised.

Another drawback of model based controllers is that senior control specialists are required support and maintain the controller. Many factories are outsourcing these control resources, increasing response times to production failures while the control specialist is accessing the factory. In this situation, the standard mechanic must request an outside control specialist when a controller related failure occurs if he is unfamiliar with that controller. This specialist may not be available until the next day. Thus the controller life cycle cost increases because the factory must have high-level control system support on staff or risk down production. Either situation drives up overall product production cost.

ASYMPTOTIC APPROACH ALGORITHM (PATENT PENDING)

IDEAL CONTROLLER RESPONSE

When a process variable is to be moved from its current position to a new setpoint, the ideal process variable response is a unit step function, except in cases where the process variable rate of change must be controlled. Unfortunately a true unit step function process variable response is not obtainable using current technology. An obtainable system response is one in which a small "knee" occurs where a rapidly changing process variable becomes close to the setpoint.

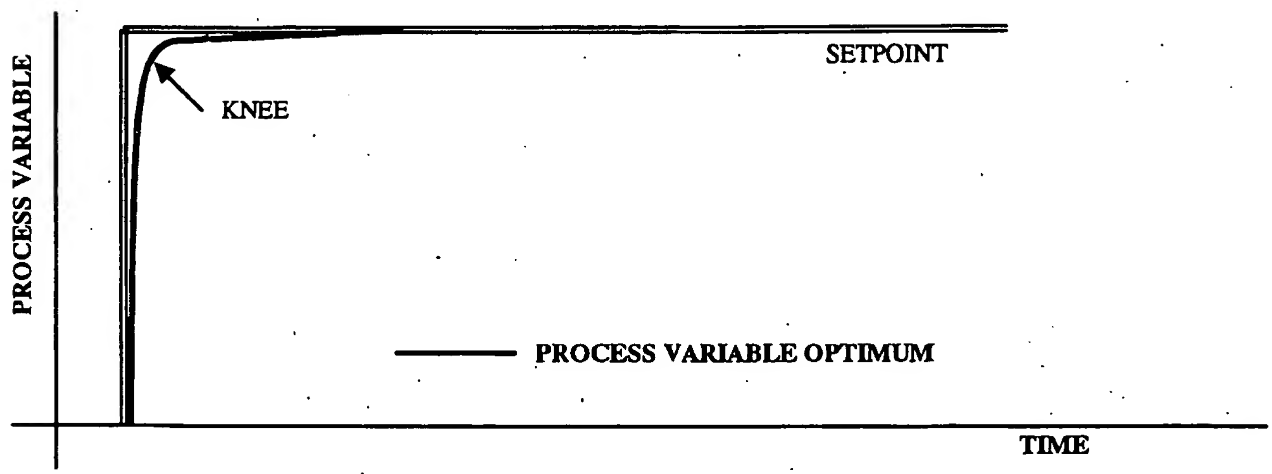


Figure 5: Ideal Process Variable Performance

The shape of this desired curve is one of an inverted polynomial equation having the form:

$$Y = A(x)^P + B(x) - C \qquad (1)$$

ASYMPTOTIC APPROACH ALGORITHM DESCRIPTION

BASE CALCULATION

When the above polynomial equation is applied to process control applications, the error is used as the "X" term and the output is used as the "Y" term. The equation takes the form of:

$$Output = K_a(Error)^P + K_b(Error) - K_{Bias}. \qquad (2)$$

where:

K_a	is	Term 1 Gain (unitless)
P	is	Polynomial Term (unitless)
K_b	is	Term 2 Gain (unitless)
K_{Bias}	is	Output Bias (unitless)

The desired inverted polynomial equation results with the process variable following the inverted polynomial equation approach to setpoint.

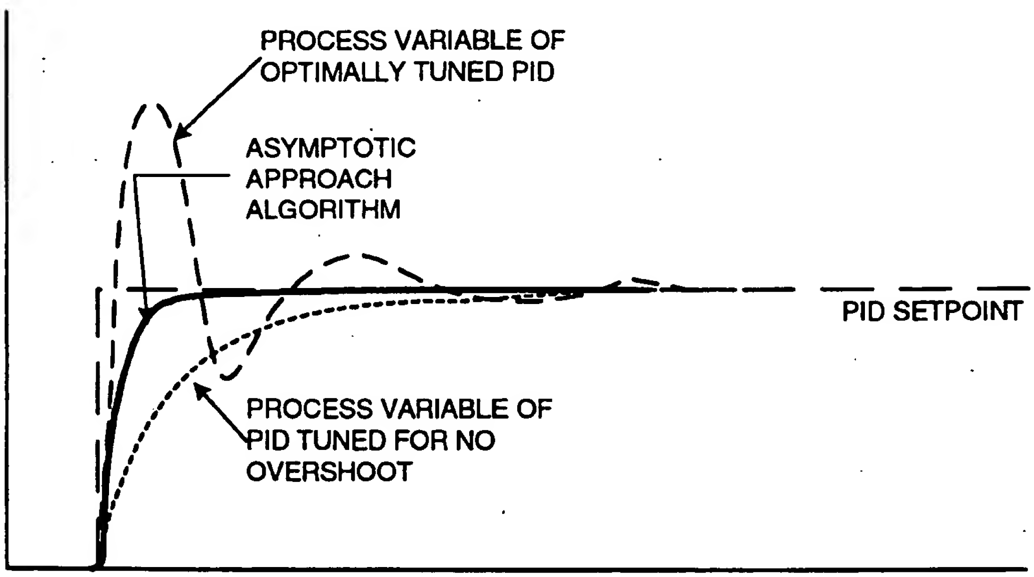


Figure 6: Different Controller Performance Curves

If the P term is odd (3, 5, 7,...), the output will be 0 if the error is negative. However, this is not the case if the P term is even. Therefore, a comparison function, inserted between the error calculation and the polynomial calculation, is required in the algorithm to ensure the error is positive. This guarantees the controller is 0 if the error is ≤ 0.

In systems containing non-negligible time delays between final control element change and process variable reactions, small overshoots will occur while this dead time is moving through the control loop. To counteract the dead time, a bias is subtracted in the polynomial equation, the constant term, forcing the output to 0 in time to prevent overshoot. Because this constant value may change over time with equipment degradation, environmental changes or other factors, an automated method to improve the bias value is included.

MODIFIED INTEGRATING OUTPUT ADJUSTMENT

After the setpoint is initially moved from its starting point to the final setpoint, a bias typically remains. To overcome this bias, the error signal is integrated over time and added to the output. This is similar to

the integral function of the PID algorithm with a significant difference: if the process variable exceeds the setpoint, either high or low, the accumulated integral value is set to 0.

Traditional PID algorithms suffer from integral wind-up. Integral wind-up is when the integration history, the error term integrated over time and added to the output, causes the process variable to move beyond the setpoint. Integral wind-up is the process controller equivalent to mechanical inertia. This inertia is often undesirable whether in a mechanical system or in a process control system. By setting the accumulated integral history to 0, the integral contribution to the output is temporarily interrupted; the inertia has the brakes applied and stops.

Most controllers include Anti-Reset-Wind-up methods to minimize the inertia problem. However, many of the controller methods activate only when the output is outside predefined limits (xi); for example, outside 0% and 100%. While other methods are more proactive in preventing overshoot, these methods allow the controller output to remain greater than zero in overshoot or undershoot conditions.

ASYMPTOTIC APPROACH OPERATIONAL DESCRIPTION:

BASE CALCULATION

If the measured value is less then setpoint for reverse acting processes or the setpoint is less than the measured value for direct acting processes, the controller output is calculated:

1. $Error = (Setpoint - Measurement)$ for reverse acting processes or (3)
   $Error = (Measurement - Setpo\text{int})$ for direct acting processes. (4)
2. If $Error$ is less than 0 set the $Output$ to 0.
3. $Output = K_a(Error)^P + K_b(Error) - K_{Bias}$ (5)
4. If the $Output$ is greater than 100%, set $Output$ to 100%
5. If the $Output$ is less than 1%, set the $Output$ to 0.
6. If the $Error$ is less than E_i (process variable units) quantity for E_t (seconds) time, check output bias quality as follows:
   - If $Error$ is greater than K_{Bias_adj}, $K_{Bias\_New} = K_{Bias} + (\frac{Error}{2})$ (6)
   - Set K_{Bias} to K_{Bias_New}
7. At same time point as Step 5 above, initiate modified integration output adjustment.
   where:

E_i	is	Error at which integral correction initiates (process variable units)
E_t	is	Time delay after E_i is reached before integral correction initiates (seconds)

Otherwise, the $Output$ is set to calculated $Output$ in 2.

If the measured value is greater than setpoint, the output is set to 0 and the integral stack is cleared by setting all registers to 0.

MODIFIED INTEGRATING OUTPUT ADJUSTMENT

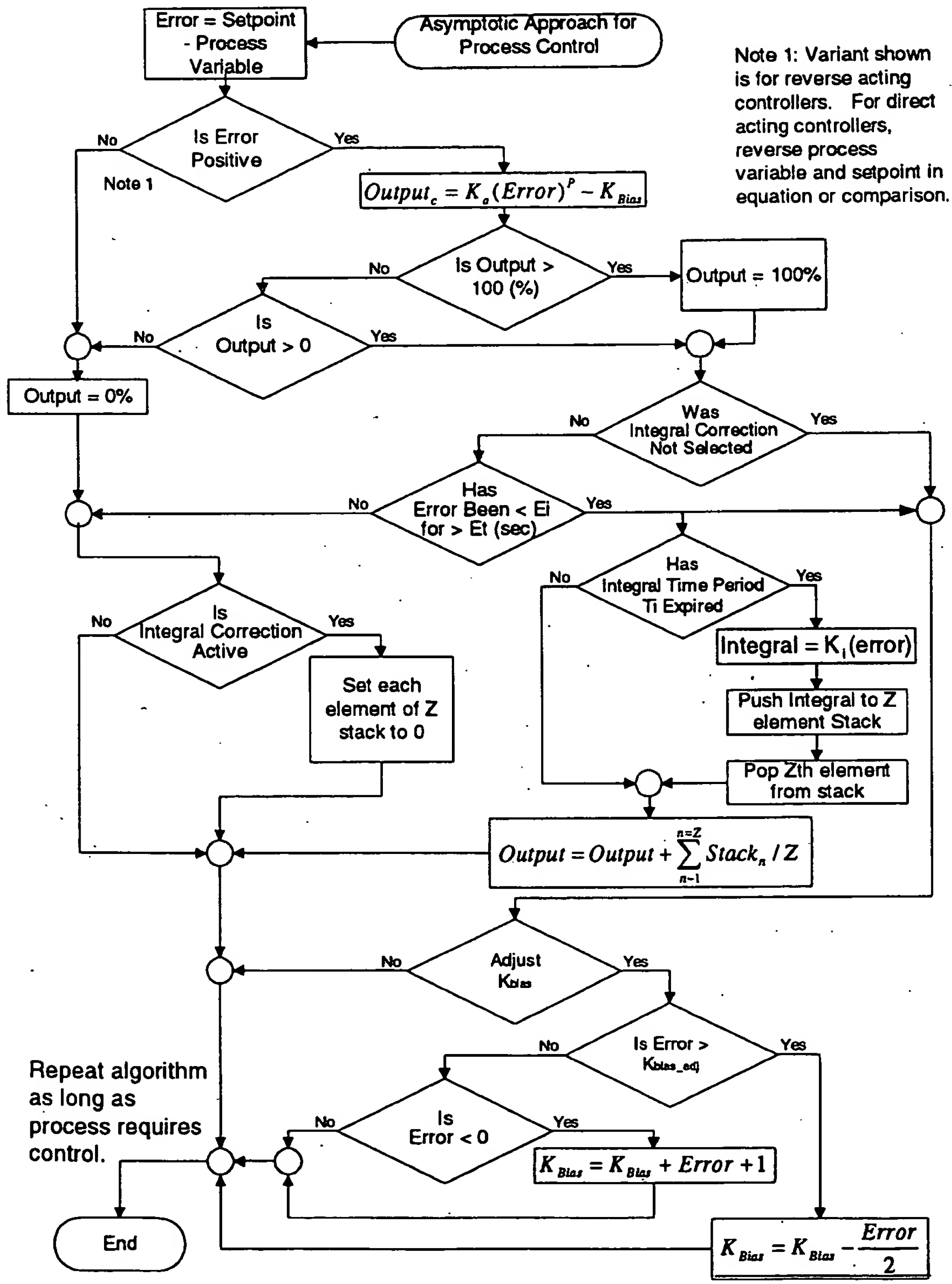
Each integral time interval I_t, an integration value is calculated:

$$Integral = K_i(error) \tag{7}$$

This integration value (*Integral*) is pushed on to a *Z* element First-In-First-Out (FIFO) error correction stack. The Z^{th} element of the stack is popped to prevent the stack from saturating.

Each stack register is added to the *Output*. The final control variable percentage is increased above the *Output* calculated in 2 to compensate for unidentified dynamic system disturbances.

FLOW CHART
(Patent Pending)
The following defines the asymptotic approach algorithm:



RESULTS

The first application for the asymptotic approach algorithm was on a fermenter in a brewing process. The fermentation optimizes when the process temperature is a held just below the point where the enzymes are killed. However, the heating rate of the vessel does not affect the process. This application has the conflicting goals of rapidly moving the process variable to setpoint without the process variable overshooting the setpoint. The heating of this 6000-gallon fermenter had been controlled by traditional PID algorithm tuned for no overshoot. The Asymptotic Approach algorithm replaced the PID algorithm with the asymptotic approach algorithm configured for a small knee, the exponent, "*p*" term, was set to a relatively high value. The total batch cycle time for the 6000-gallon fermenter was reduced by ten percent when compared to the PID algorithm tuned for no overshoot. This reduction is a direct decrease to the product production cost and a direct increase in profitability.

The asymptotic approach algorithm was also applied to a drum filling station. The drums are filled to approximately 620 pounds at a rate of 200 pounds per minute. This is an application where the process variable must be moved rapidly to the setpoint. Overshoot, while allowed by the customer (the customer receives more product for free), reduces profits and must be avoided. The asymptotic approach algorithm resulted in the drums being filled to the setpoint within the resolution of the scale, which is one pound.

CONCLUSION

The Asymptotic Approach algorithm is not a complete replacement for PID or other algorithms. For example, the PID algorithm will still provide the minimum integrated absolute error (xii) in continuous control applications that can tolerate overshoot. However, Asymptotic Approach does provide significant advantages in applications that cannot tolerate overshoot: near ideal response, safeguards against overshoot, maintaining the process variable under automatic control throughout the batch and economical to deploy.

BOTTOM LINE

The Asymptotic Approach algorithm provides the best balance of ideal response, reduced production cycle times, and economic implementation of currently available control strategies in applications where overshoot must be prevented. The result is the Asymptotic Approach algorithm provides the best value for control system expenditures in these applications.

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